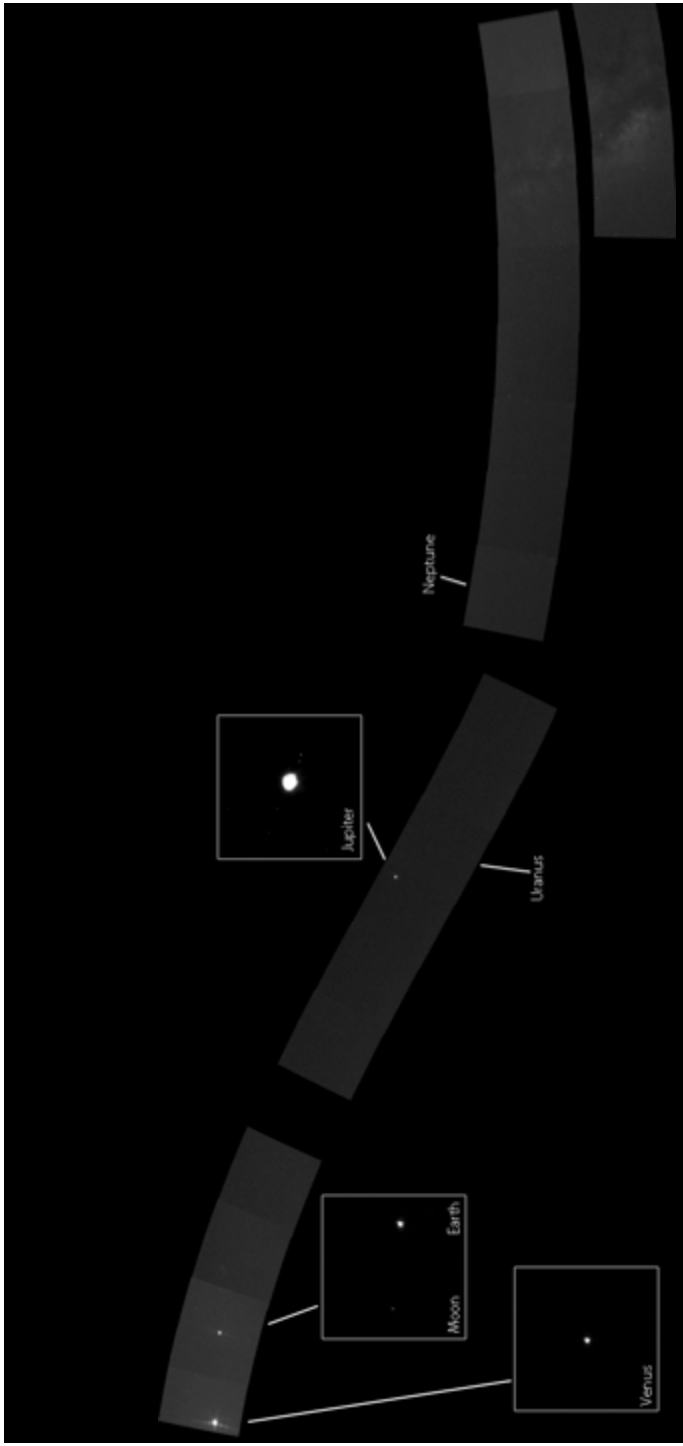


Expanding into the Solar System

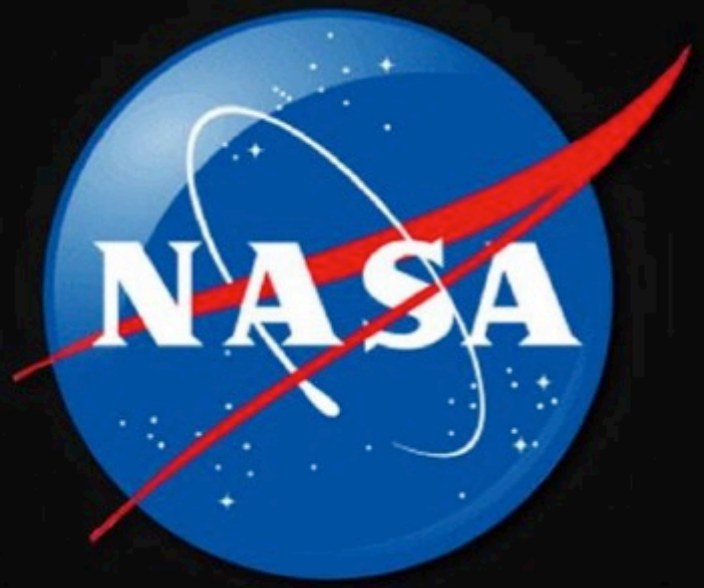
Matt Daniels
Special Projects & Studies
NASA Ames Research Center

December 5, 2014

Science

Earth

Human Expansion



Science

-Universe

-Life

Earth

Human Expansion


Science
-Universe
-Life
Earth
Human
Expansion

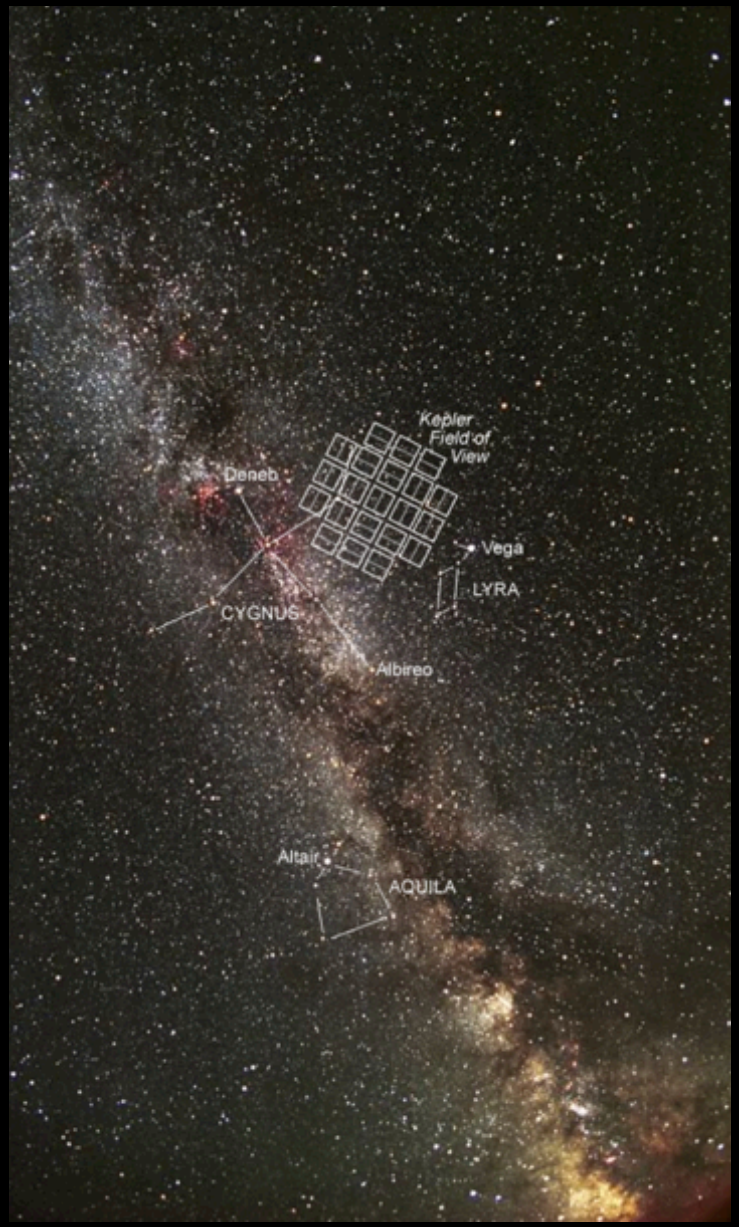
Science

-Universe

-Life

Earth

Human Expansion



Science

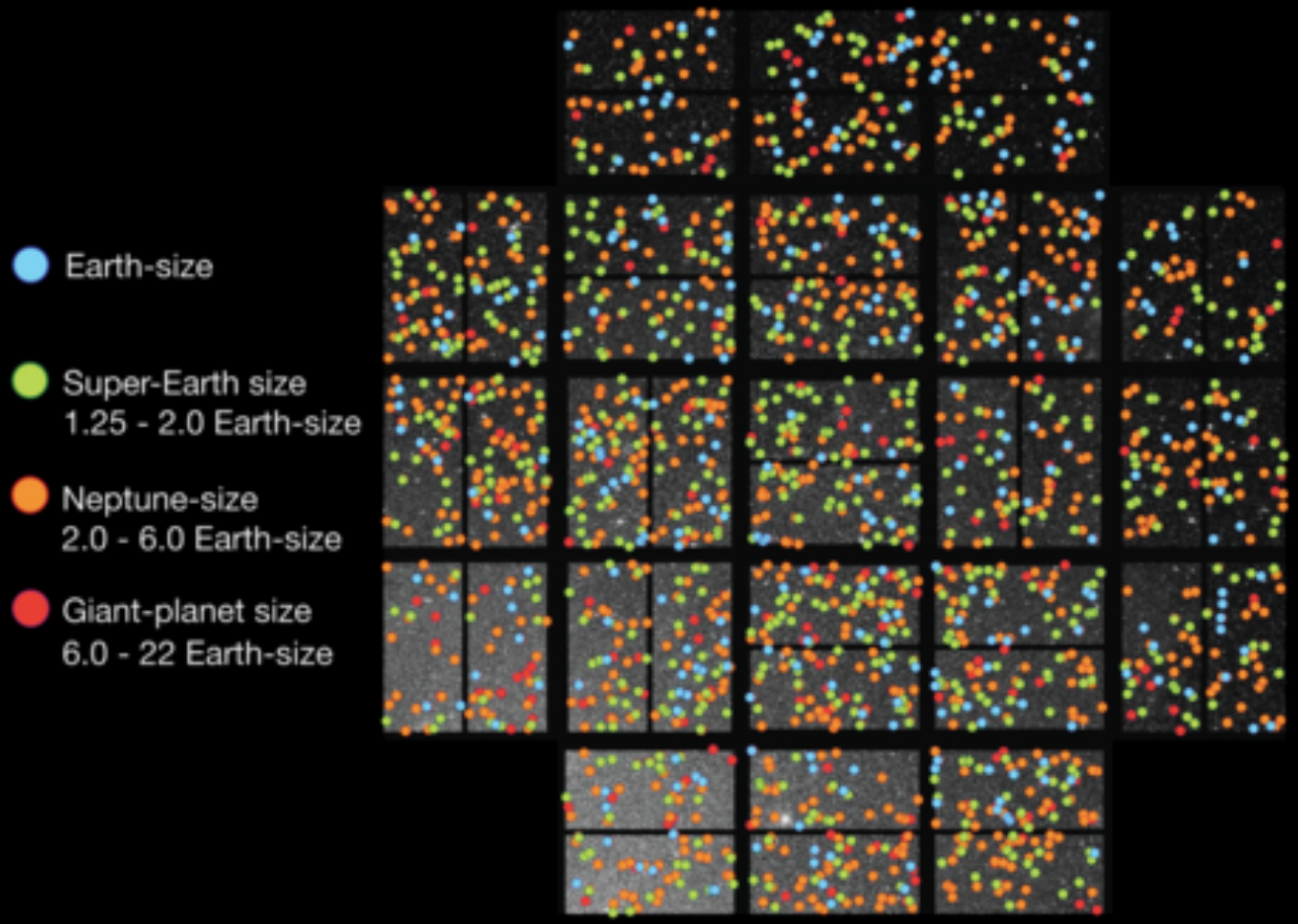
-Universe

-Life

Earth

Human Expansion

Locations of Kepler Planet Candidates as of January 7, 2013



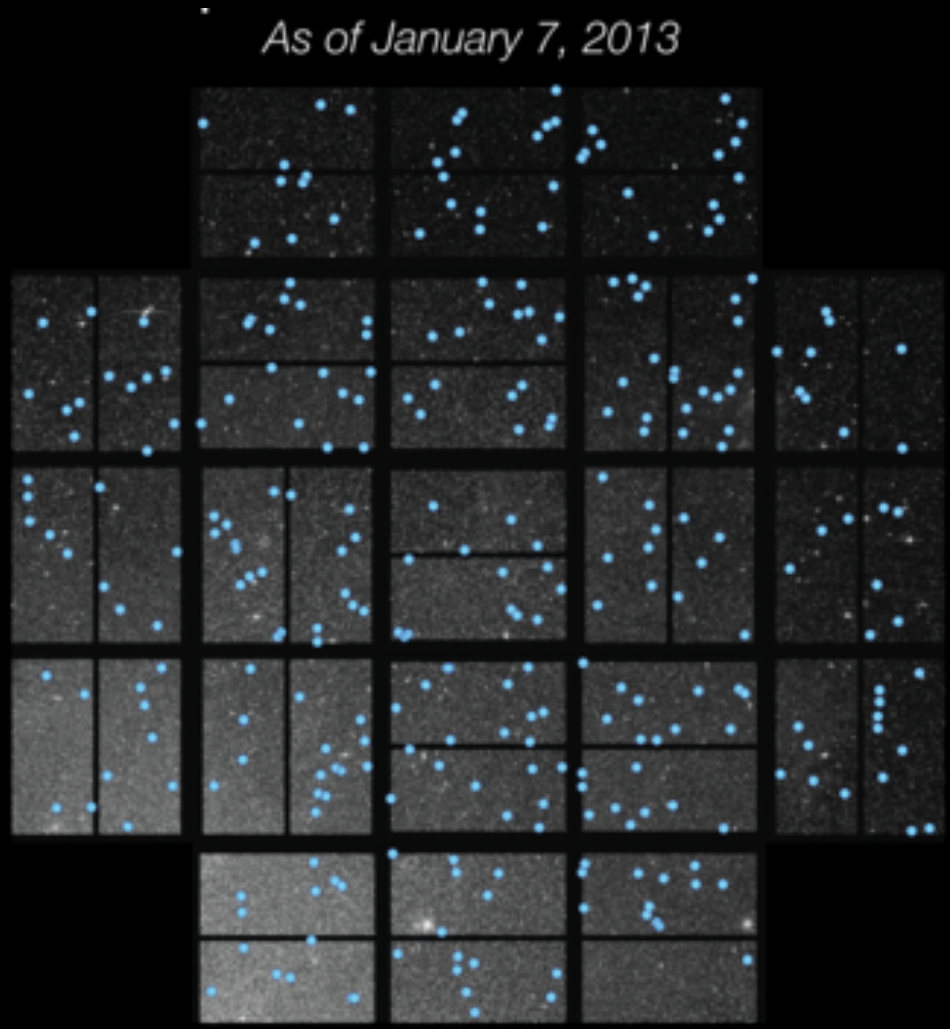
Science

-Universe

-Life

Earth

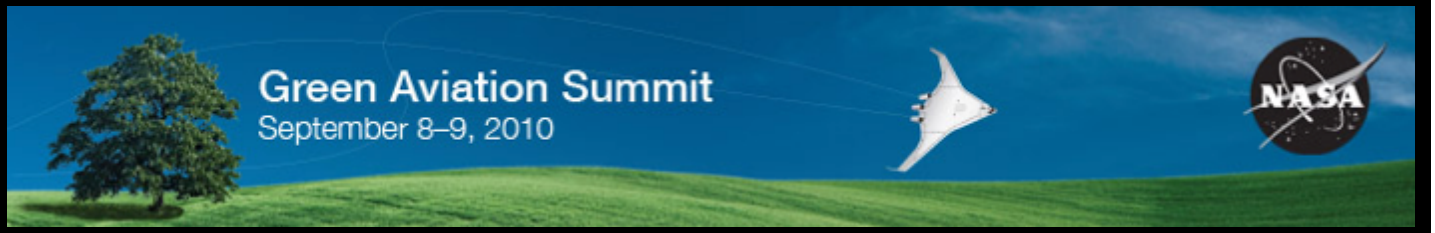
Human Expansion

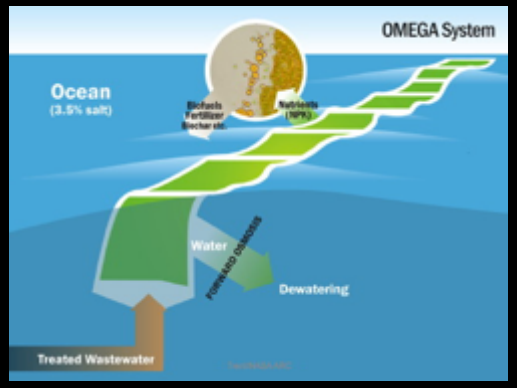


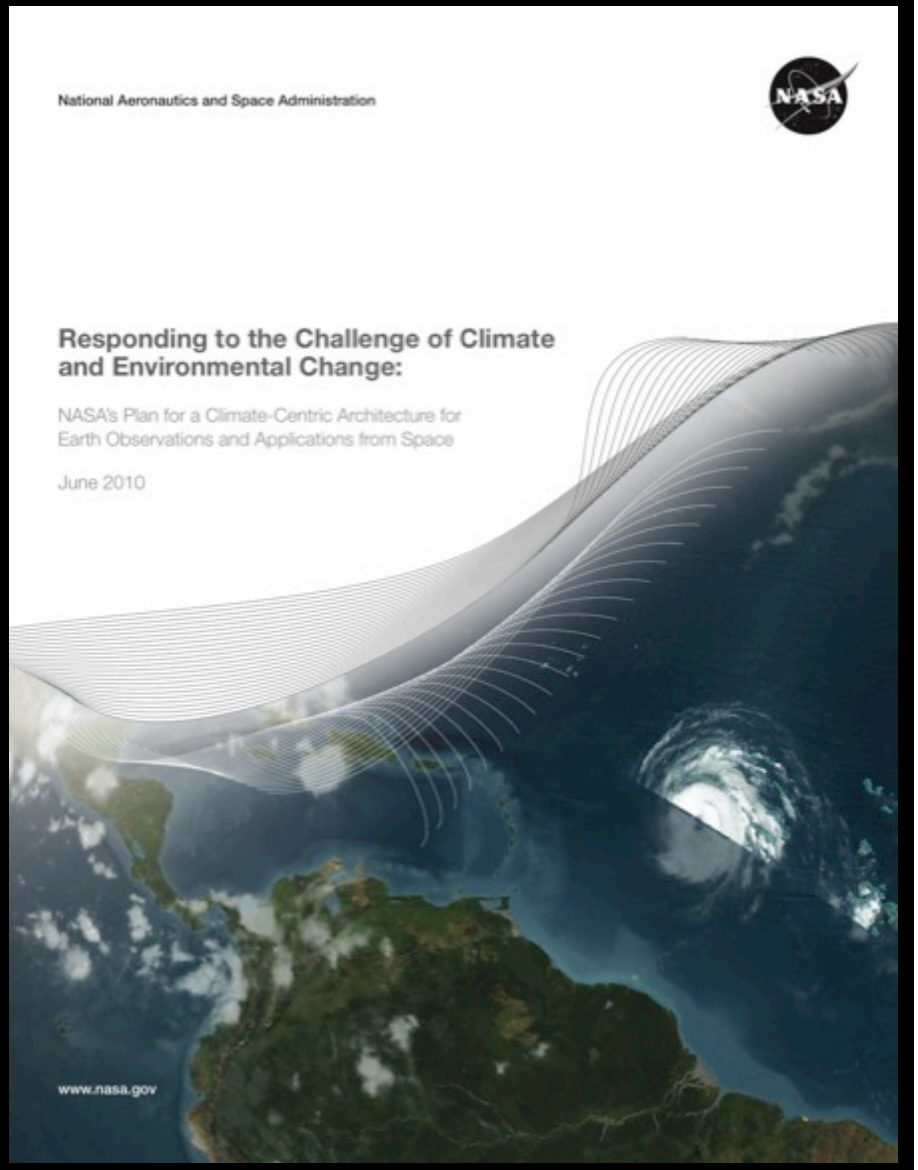
Science

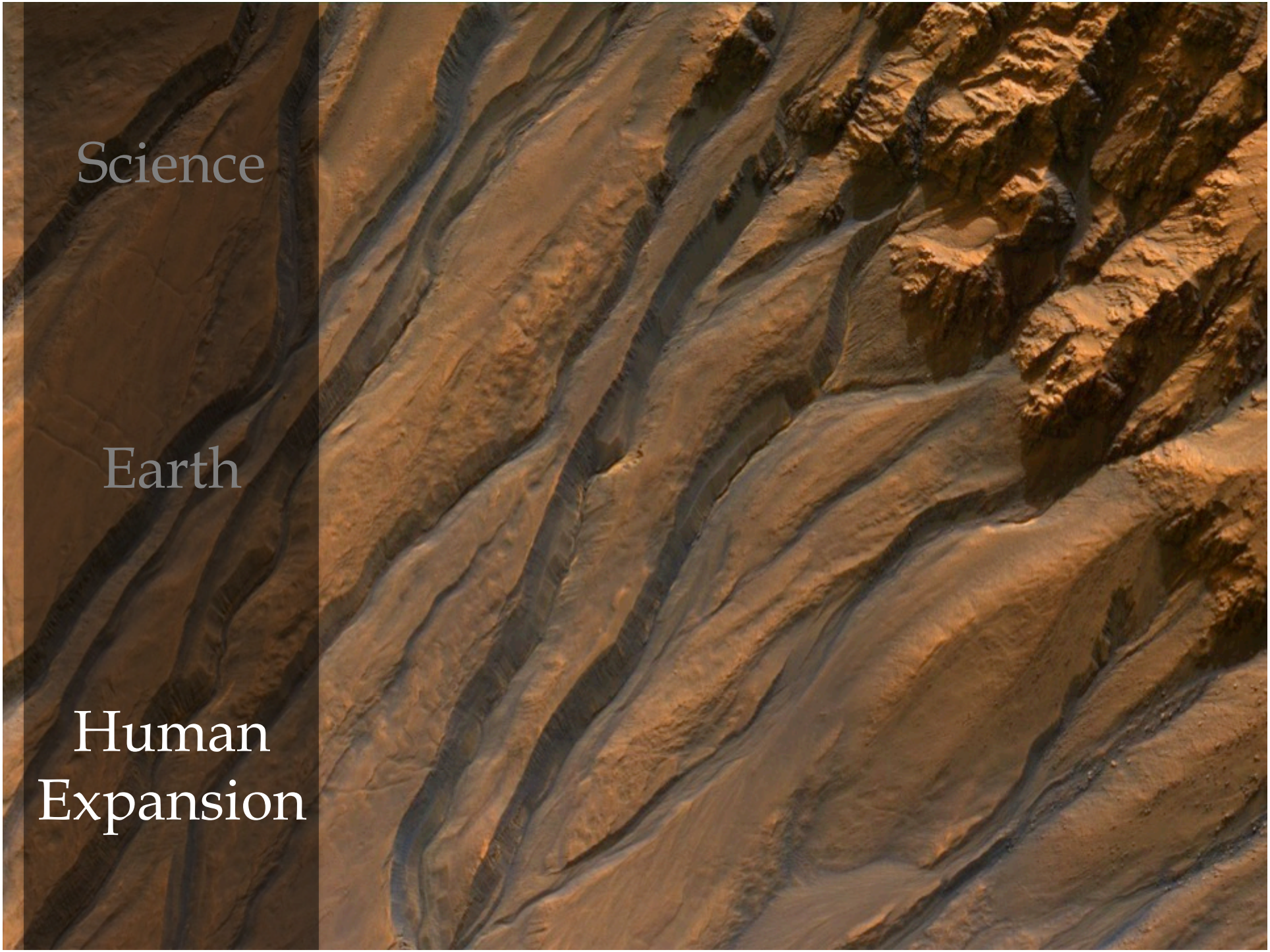
Earth

Human Expansion








Science
Earth
Human
Expansion

How do we think about the long future?

Before the "aerospace era"	The aerospace era	Now	
1800s - 1950	1950-2000	2000-2020	21st century

How do we think about the long future?

Before the "aerospace era"	The aerospace era	Now	
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"By 1958, private investments in over 40 U.S. observatories totaled about $8 billion in 2012 dollars, and nationwide rocket clubs and test sites laid the first foundations of the American space community." [1]

[1] **Source: MacDonald, Alexander, "The Long Space Age: An Economic Perspective on the History of American Space Exploration," (PhD dissertation, University of Oxford, 2012).**

Lick Observatory
Private Endowment
1876

How do we think about the long future?

Before the "aerospace era"	The aerospace era	Now	
1800s - 1950	1950-2000	2000-2020	21st century

Lick (1796-1876): $1.2B (current USD) to Lick Observatory
Guggenheim (1856-1930) and family: $36M (current USD) for Robert Goddard
Carnegie (1835-1919): $630M (current USD) to Mount Wilson Solar Observatory

[1] **Sources: MacDonald, Alexander, "The Long Space Age: An Economic Perspective on the History of American Space Exploration," (PhD dissertation, University of Oxford, 2012). NASA, "Emerging Space: the Evolving Landscape of 21st Century American Spaceflight, 2014.**

How do we think about the long future?

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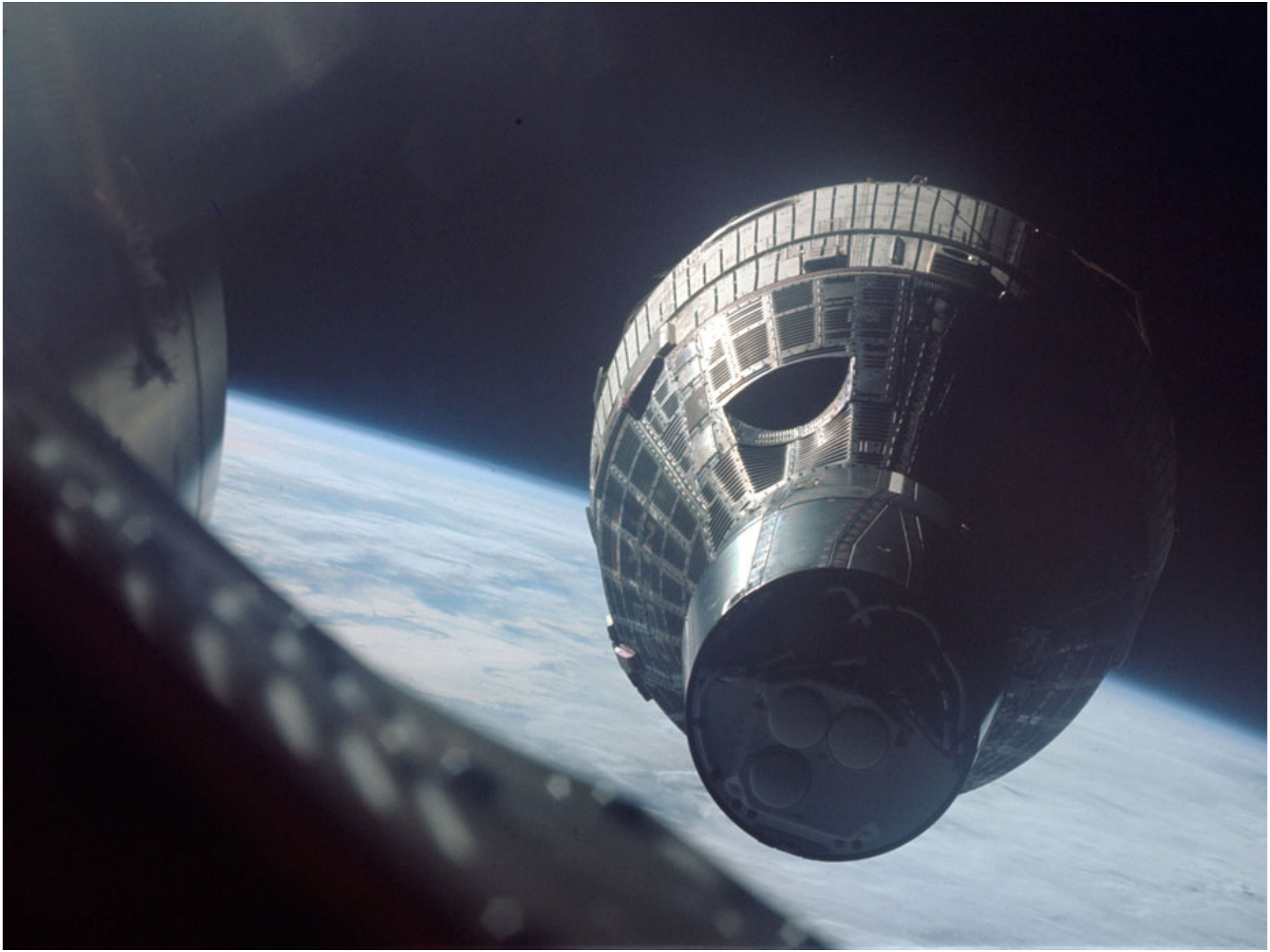


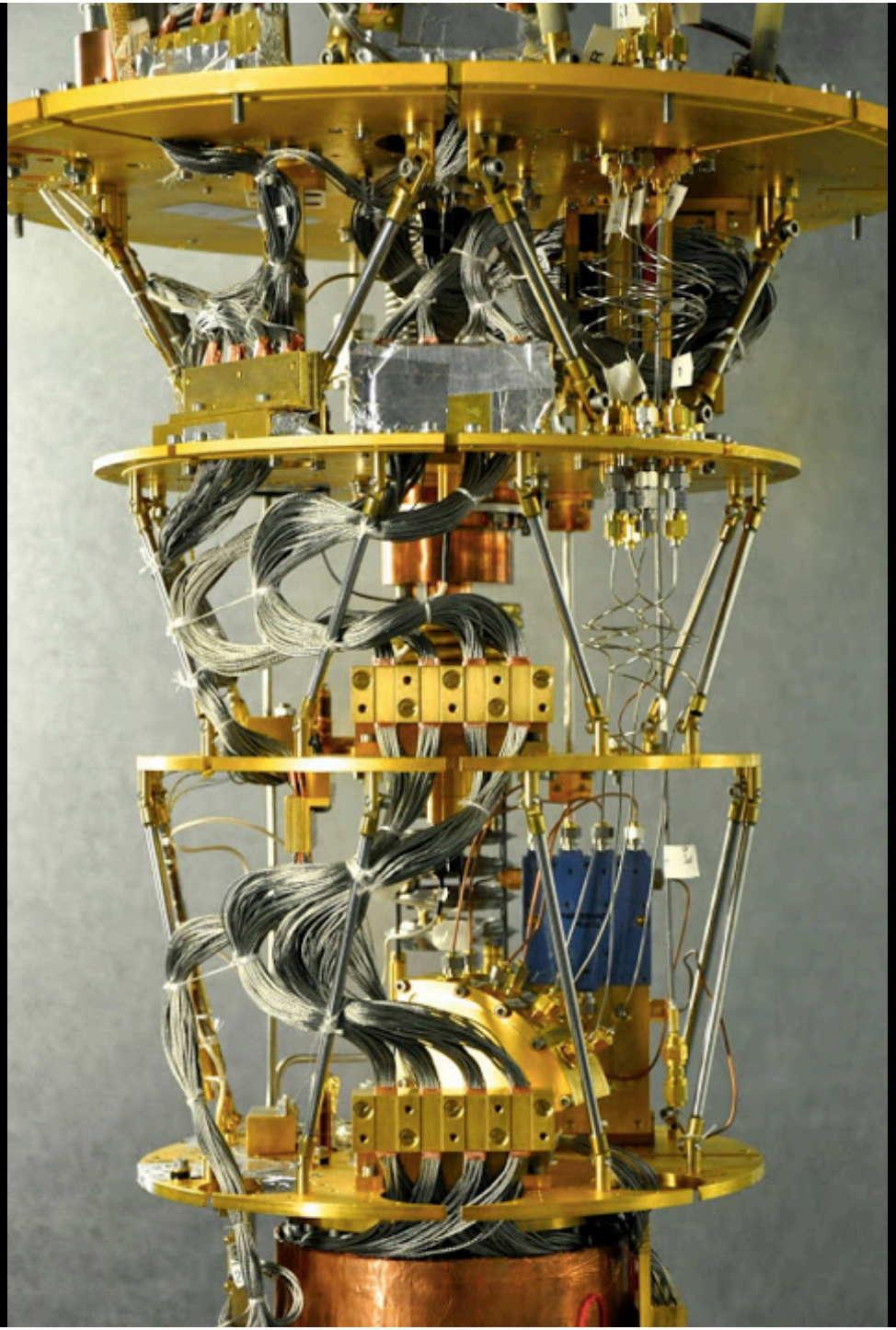
How do we think about the long future?

Before the "aerospace era"	The aerospace era	Now	
1800s - 1950	1950-2000	2000-2020	21st century

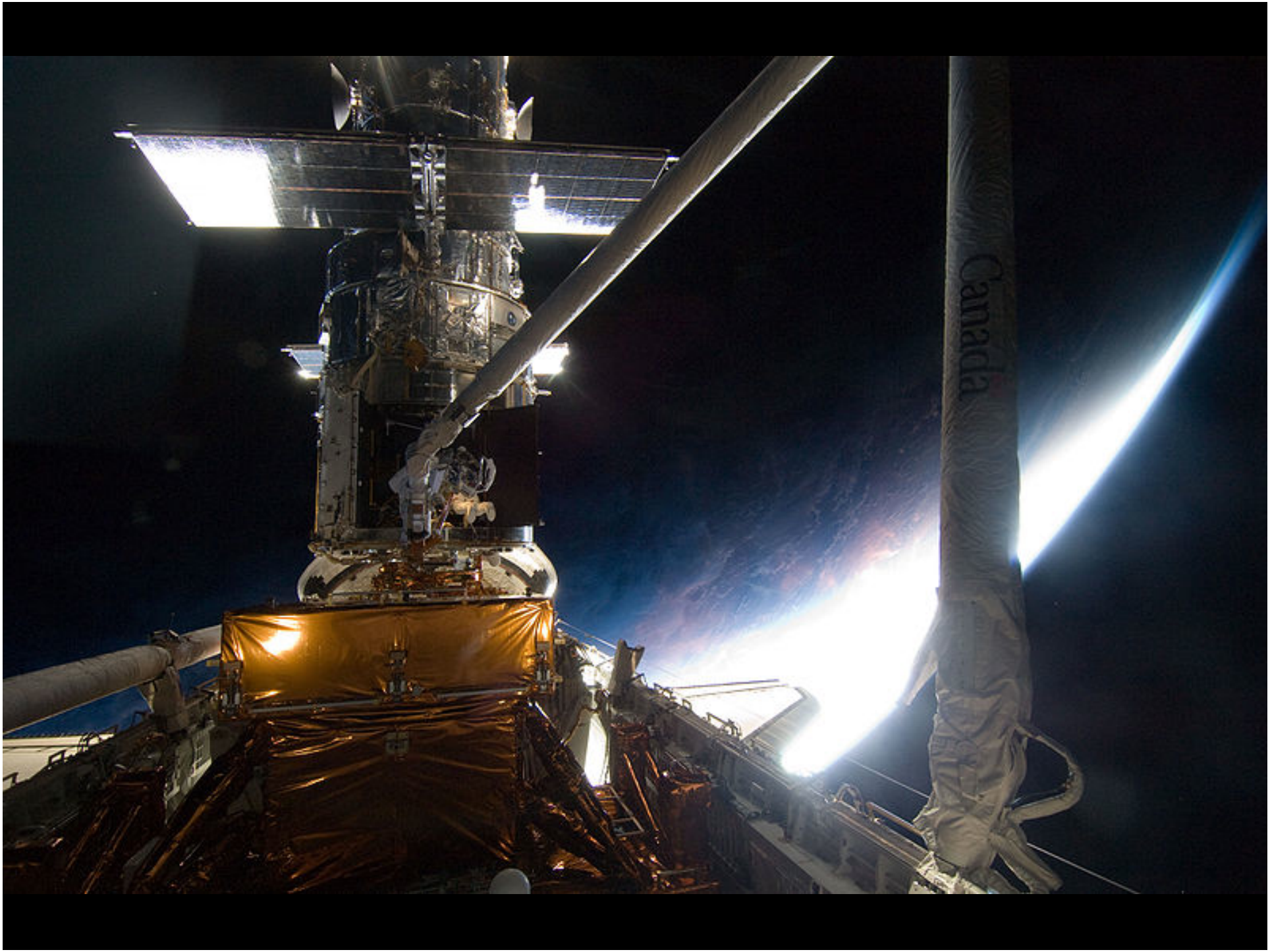
Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome

Daniel G. Gibson,[1] John I. Glass,[1] Carole Lartigue,[1] Vladimir N. Noskov,[1] Ray-Yuan Chuang,[1] Mikkel A. Algire,[1] Gwynedd A. Benders,[2] Michael G. Montague,[1] Li Ma,[1] Monzia M. Moodie,[1] Chuck Merryman,[1] Sanjay Vashee,[1] Radha Krishnakumar,[1] Nacyra Assad-Garcia,[1] Cynthia Andrews-Pfannkoch,[1] Evgeniya A. Denisova,[1] Lei Young,[1] Zhi-Qing Qi,[1] Thomas H. Segall-Shapiro,[1] Christopher H. Calvey,[1] Prashanth P. Parmar,[1] Clyde A. Hutchison III,[2] Hamilton O. Smith,[2] J. Craig Venter[1,2]*

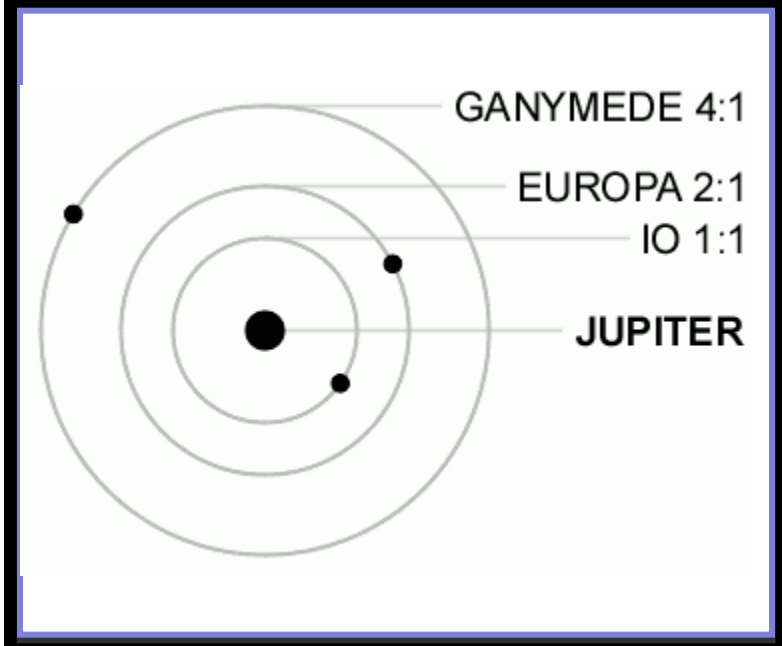
Quantum
Artificial Intelligence
Laboratory

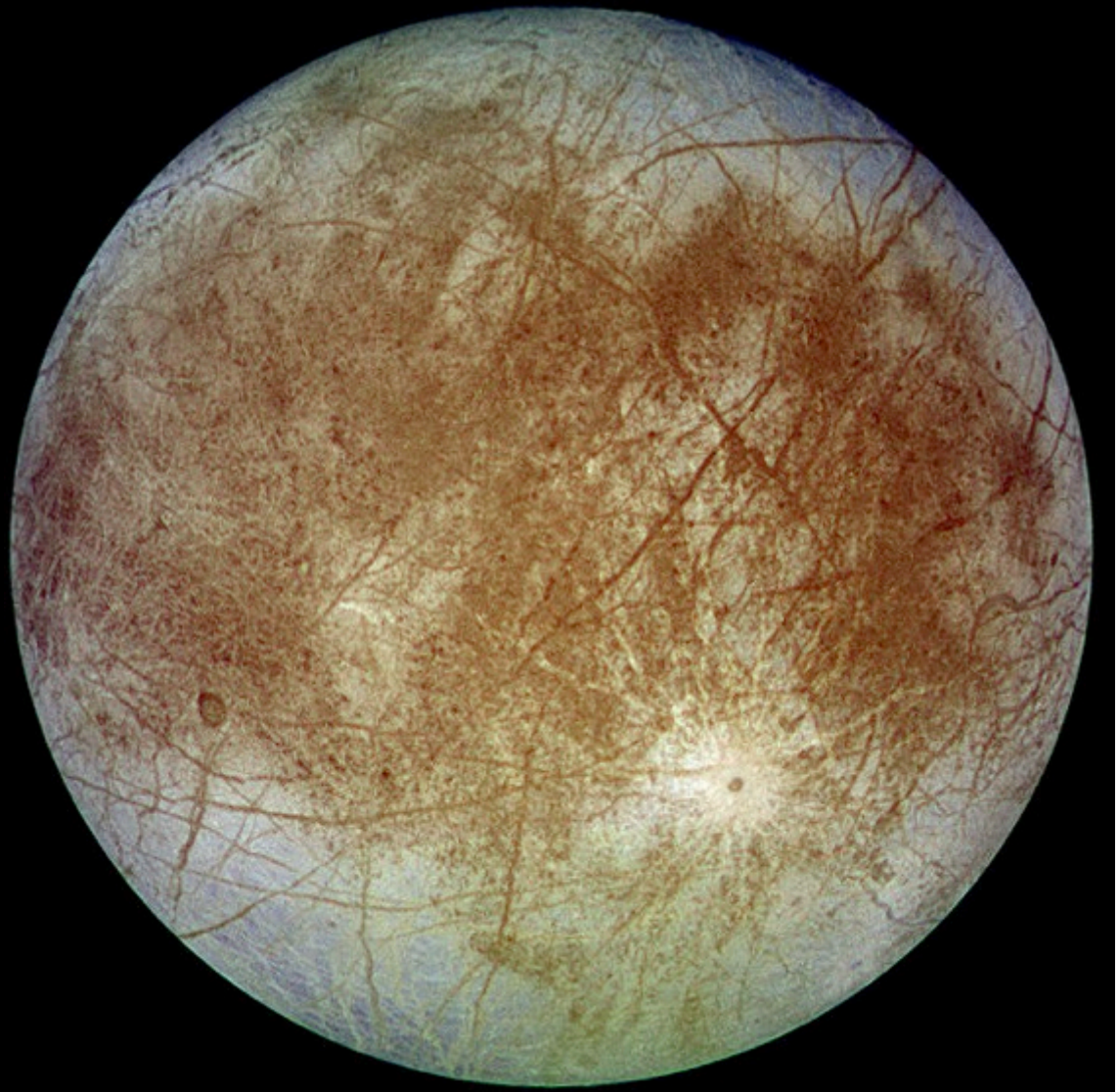



SPACEX

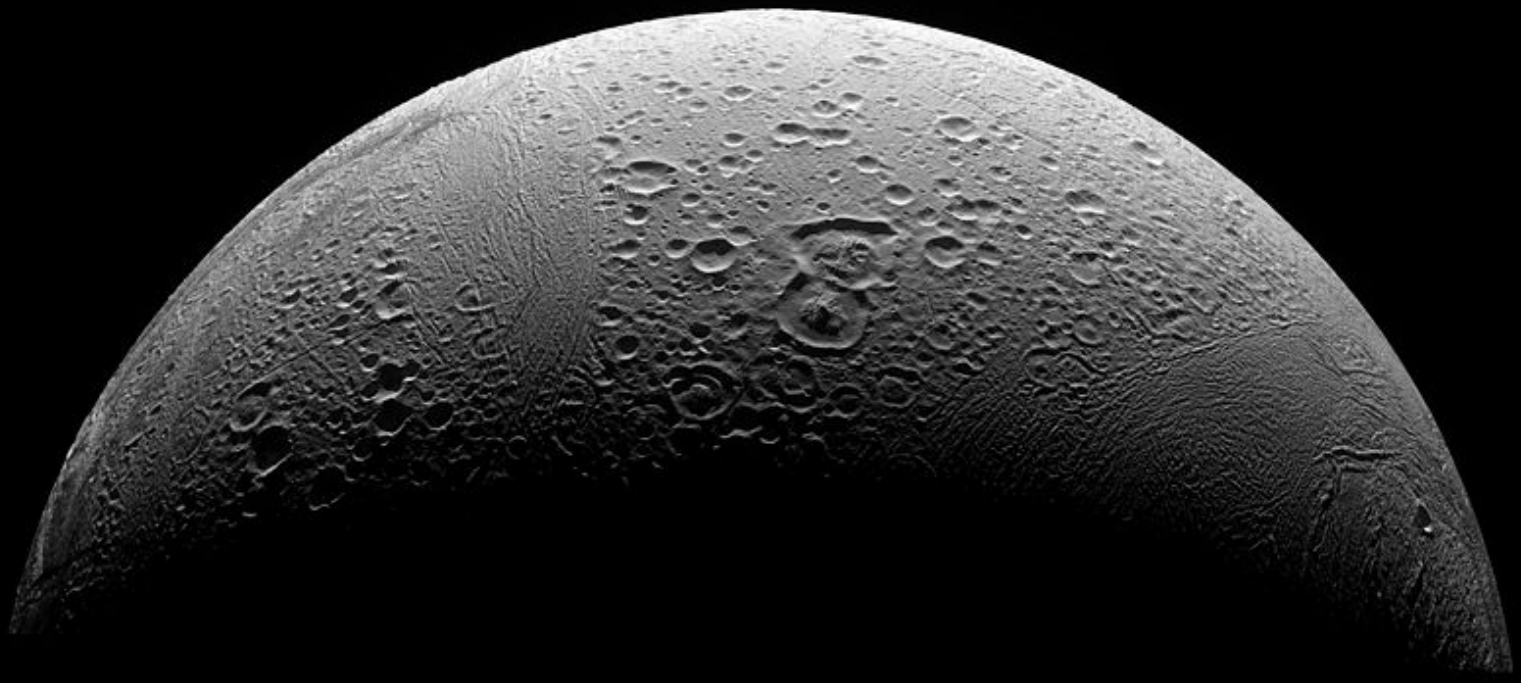

Canada

Europa

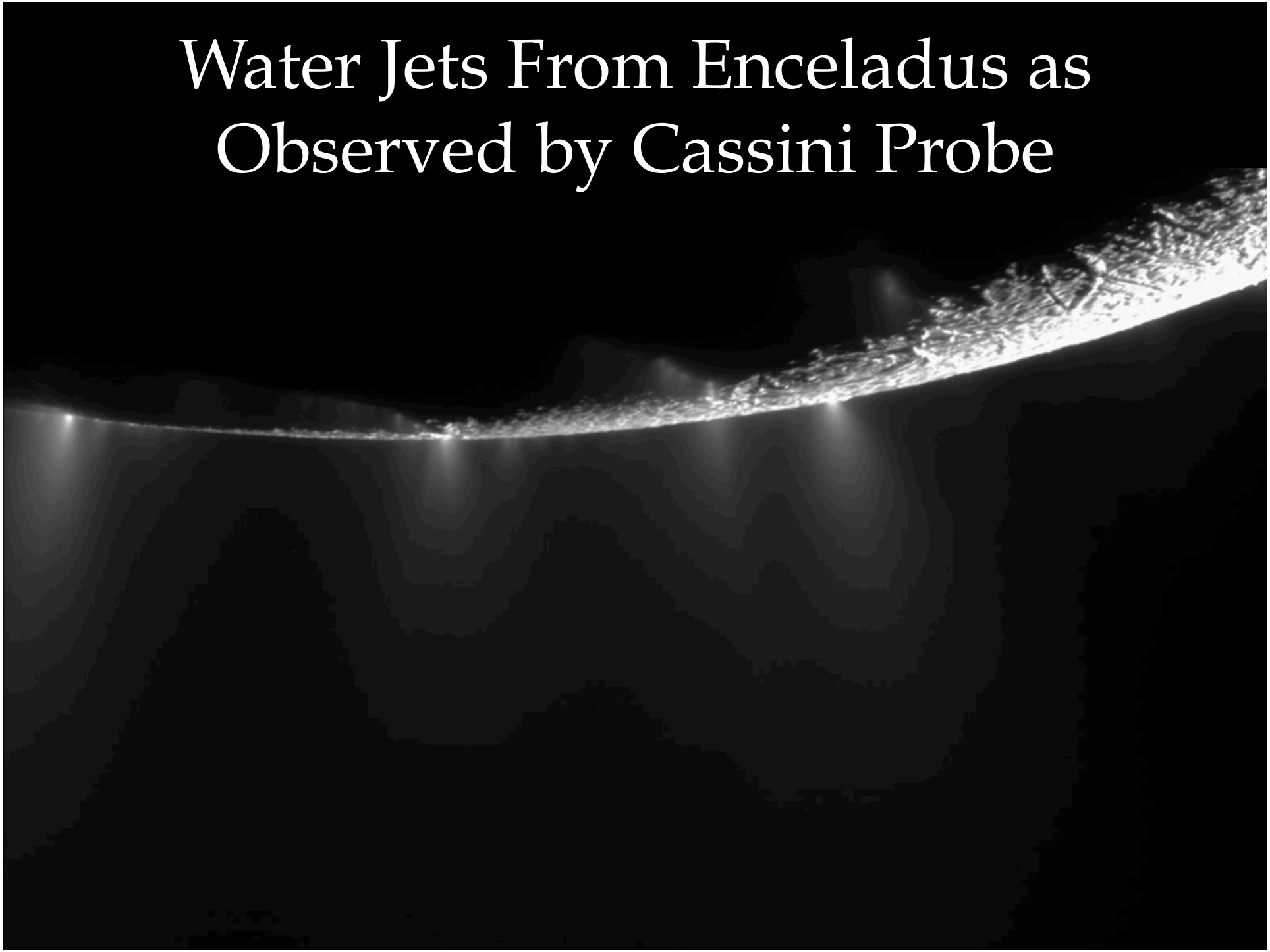


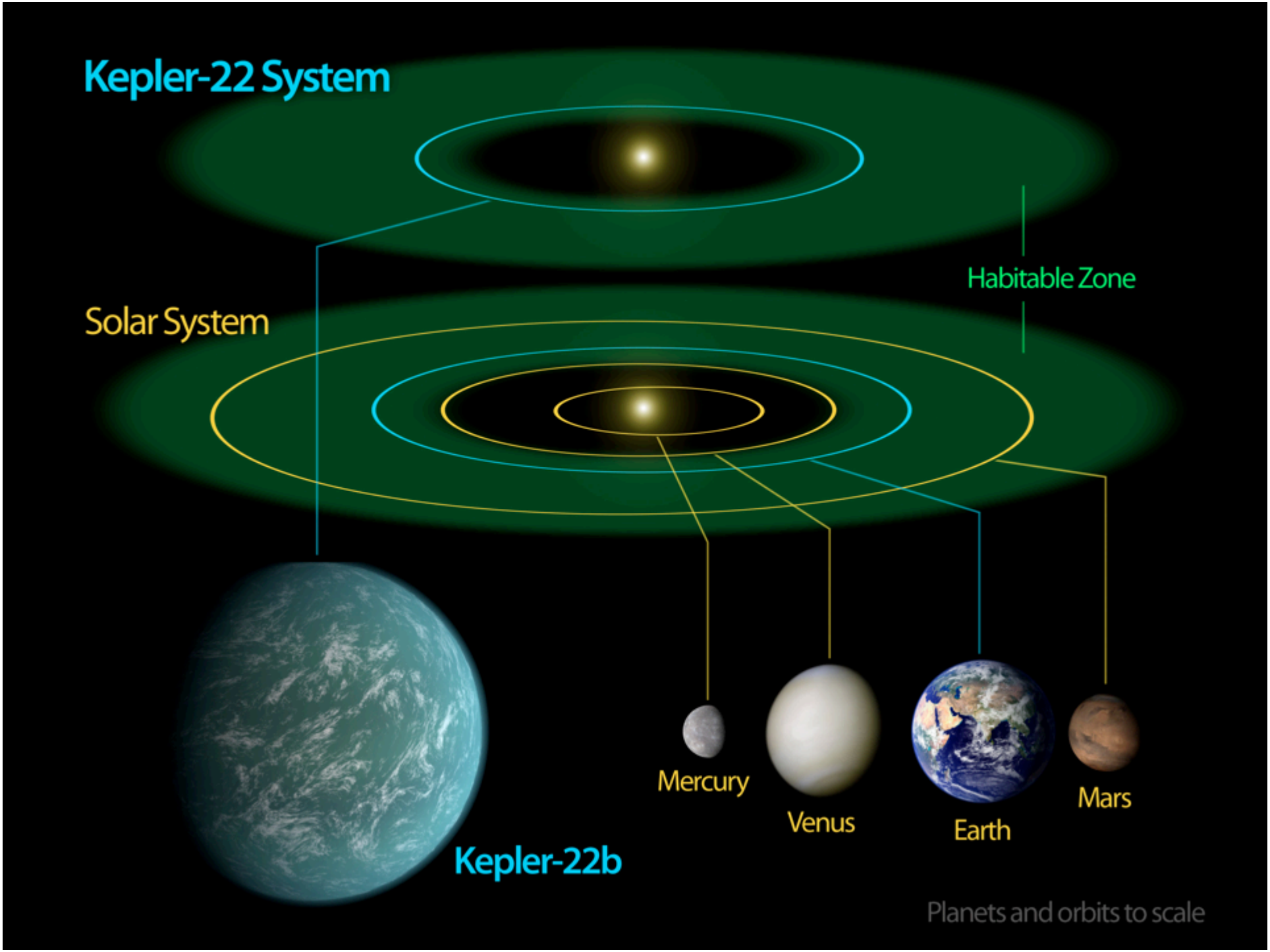


Enceladus



Water Jets From Enceladus as Observed by Cassini Probe




Kepler-22 System
Habitable Zone
Solar System
Mercury
Venus
Earth
Mars
Kepler-22b
Planets and orbits to scale

How do we think about the long future?

Before the "aerospace era"	The aerospace era	Now	
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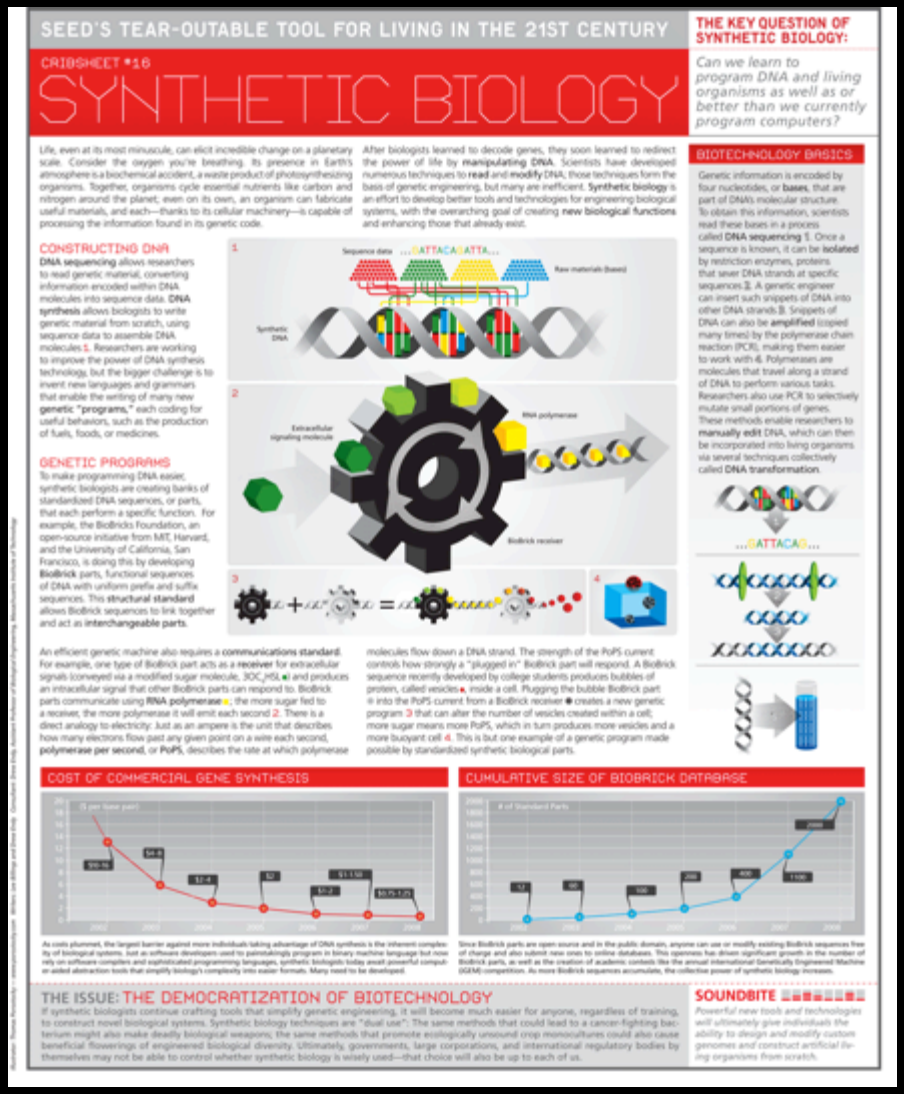
“Over the next 20 years, synthetic genomics is going to become the standard for making anything”

- J. Craig Venter, 2007, Gibson et. al, Science 2010



SEED'S TEAR-OUTABLE TOOL FOR LIVING IN THE 21ST CENTURY

CRIBSHEET #16

SYNTHETIC BIOLOGY

Life, even at its most minuscule, can elicit incredible change on a planetary scale. Consider the oxygen you're breathing. Its presence in Earth's atmosphere is a biochemical accident, a waste product of photosynthesizing organisms. Together, organisms cycle essential nutrients like carbon and nitrogen around the planet; even on its own, an organism can fabricate useful materials, and each—thanks to its cellular machinery—is capable of processing the information found in its genetic code.

After biologists learned to decode genes, they soon learned to redirect the power of life by **manipulating DNA**. Scientists have developed numerous techniques to **read** and **modify** DNA; those techniques form the basis of genetic engineering, but many are inefficient. **Synthetic biology** is an effort to develop better tools and technologies for engineering biological systems, with the overarching goal of creating **new biological functions** and enhancing those that already exist.

CONSTRUCTING DNA

DNA sequencing allows researchers to read genetic material, converting information encoded within DNA molecules into sequence data. **DNA synthesis** allows biologists to write genetic material from scratch, using sequence data to assemble DNA molecules 5. Researchers are working to improve the power of DNA synthesis technology, but the bigger challenge is to invent new languages and grammars that enable the writing of many new **genetic "programs,"** each coding for useful behaviors, such as the production of fuels, foods, or medicines.

GENETIC PROGRAMS

To make programming DNA easier, synthetic biologists are creating banks of standardized DNA sequences, or parts, that each perform a specific function. For example, the BioBricks Foundation, an open-source initiative from MIT, Harvard, and the University of California, San Francisco, is doing this by developing **BioBrick** parts, functional sequences of DNA with uniform prefix and suffix sequences. This **structural standard** allows BioBrick sequences to link together and act as **interchangeable parts**.

An efficient genetic machine also requires a **communications standard**. For example, one type of BioBrick part acts as a **receiver** for extracellular signals (conveyed via a modified sugar molecule, $3OC_6HSL$ ●) and produces an intracellular signal that other BioBrick parts can respond to. BioBrick parts communicate using **RNA polymerase** ●: the more sugar fed to a receiver, the more polymerase it will emit each second 2. There is a direct analogy to electricity: Just as an ampere is the unit that describes how many electrons flow past any given point on a wire each second, **polymerase per second**, or **PoPS**, describes the rate at which polymerase molecules flow down a DNA strand. The strength of the PoPS current controls how strongly a "plugged in" BioBrick part will respond. A BioBrick sequence recently developed by college students produces bubbles of protein, called vesicles ●, inside a cell. Plugging the bubble BioBrick part ● into the PoPS current from a BioBrick receiver ● creates a new genetic program 3 that can alter the number of vesicles created within a cell; more sugar means more PoPS, which in turn produces more vesicles and a more buoyant cell 4. This is but one example of a genetic program made possible by standardized synthetic biological parts.

THE KEY QUESTION OF SYNTHETIC BIOLOGY:

Can we learn to program DNA and living organisms as well as or better than we currently program computers?

BIOTECHNOLOGY BASICS

Genetic information is encoded by four nucleotides, or **bases**, that are part of DNA's molecular structure. To obtain this information, scientists read these bases in a process called **DNA sequencing** 1. Once a sequence is known, it can be **isolated** by restriction enzymes, proteins that sever DNA strands at specific sequences 2. A genetic engineer can insert such snippets of DNA into other DNA strands 3. Snippets of DNA can also be **amplified** (copied many times) by the polymerase chain reaction (PCR), making them easier to work with 4. Polymerases are molecules that travel along a strand of DNA to perform various tasks. Researchers also use PCR to selectively mutate small portions of genes. These methods enable researchers to **manually edit** DNA, which can then be incorporated into living organisms via several techniques collectively called **DNA transformation**.

COST OF COMMERCIAL GENE SYNTHESIS

CUMULATIVE SIZE OF BIOBRICK DATABASE

As costs plummet, the largest barrier against more individuals taking advantage of DNA synthesis is the inherent complexity of biological systems. Just as software developers used to painstakingly program in binary machine language but now rely on high-level languages and automated programming languages, synthetic biologists today await powerful computer-aided abstraction tools that simplify biology's complexity into easier formats. Many need to be developed.

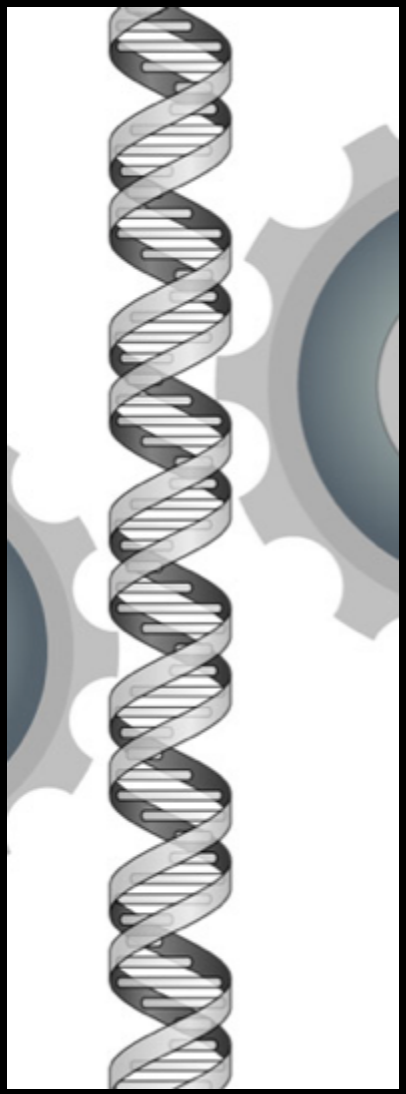
Since BioBrick parts are open source and in the public domain, anyone can use or modify existing BioBrick sequences free of charge and also submit new ones to online databases. This openness has driven significant growth in the number of BioBrick parts, as well as the creation of academic contests like the annual International Genetically Engineered Machine (iGEM) competition. As more BioBrick sequences accumulate, the collective power of synthetic biology increases.

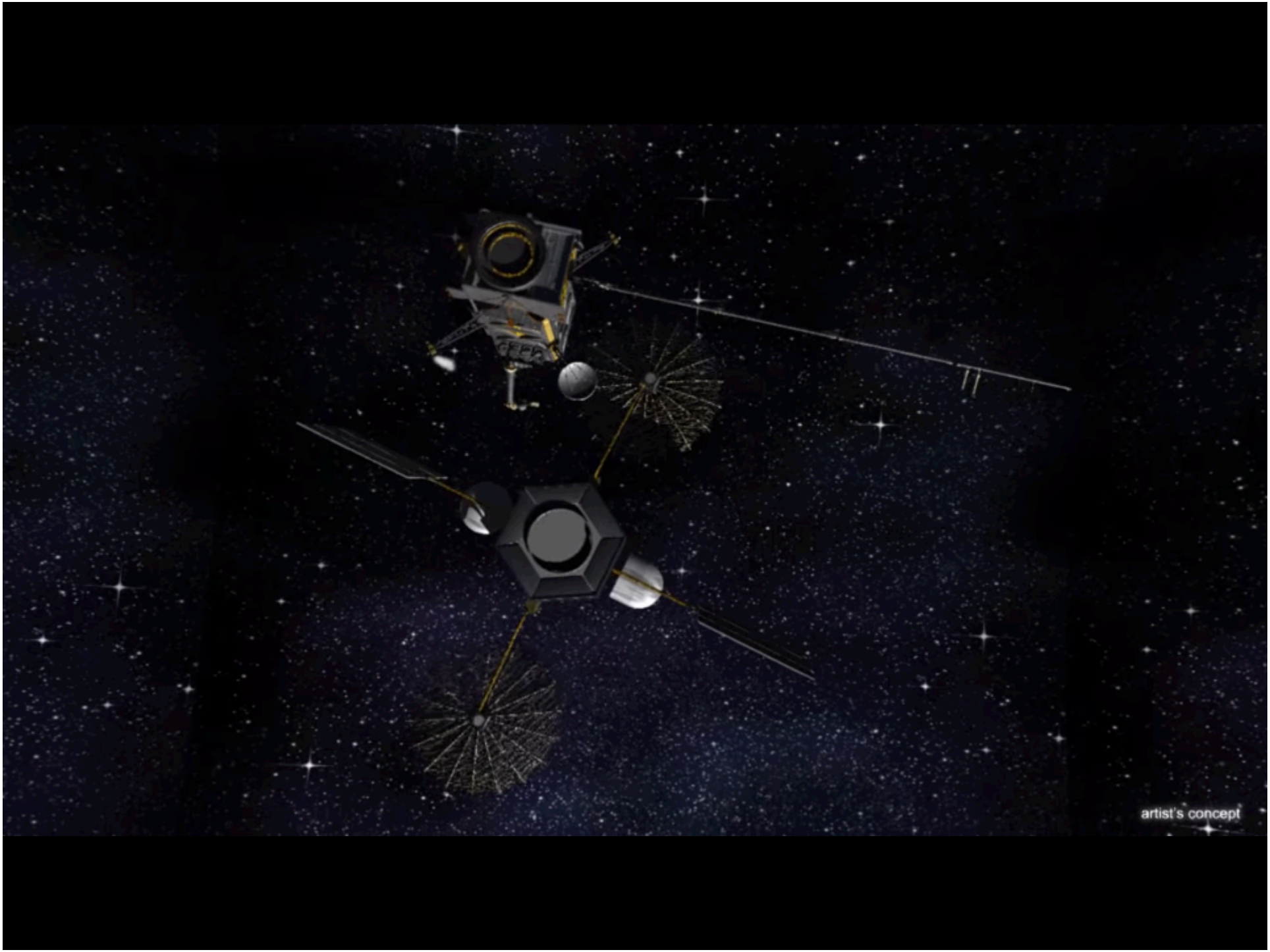
THE ISSUE: THE DEMOCRATIZATION OF BIOTECHNOLOGY

If synthetic biologists continue crafting tools that simplify genetic engineering, it will become much easier for anyone, regardless of training, to construct novel biological systems. Synthetic biology techniques are "dual use": The same methods that could lead to a cancer-fighting bacterium might also make deadly biological weapons; the same methods that promote ecologically unsound crop monocultures could also cause beneficial flowerings of engineered biological diversity. Ultimately, governments, large corporations, and international regulatory bodies by themselves may not be able to control whether synthetic biology is wisely used—that choice will also be up to each of us.

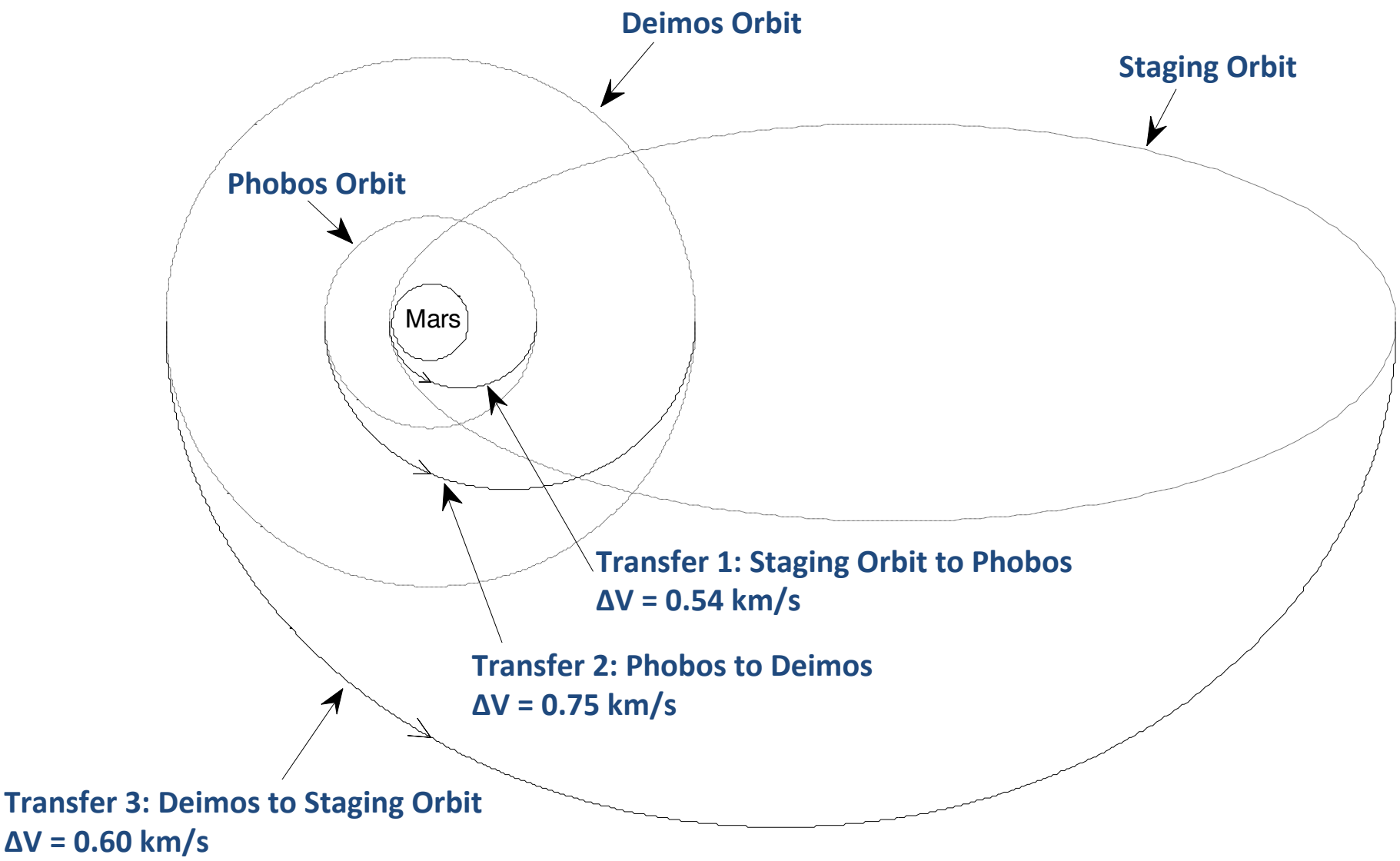
SOUNDBITE

Powerful new tools and technologies will ultimately give individuals the ability to design and modify custom genomes and construct artificial living organisms from scratch.




artist's concept

Mars System: Phobos & Deimos Rendezvous




BLUE SUNSET - (MARS)
W A N D E R E R S
A SHORT FILM BY ERIK WERNQUIST
www.erikwernquist.com/wanderers

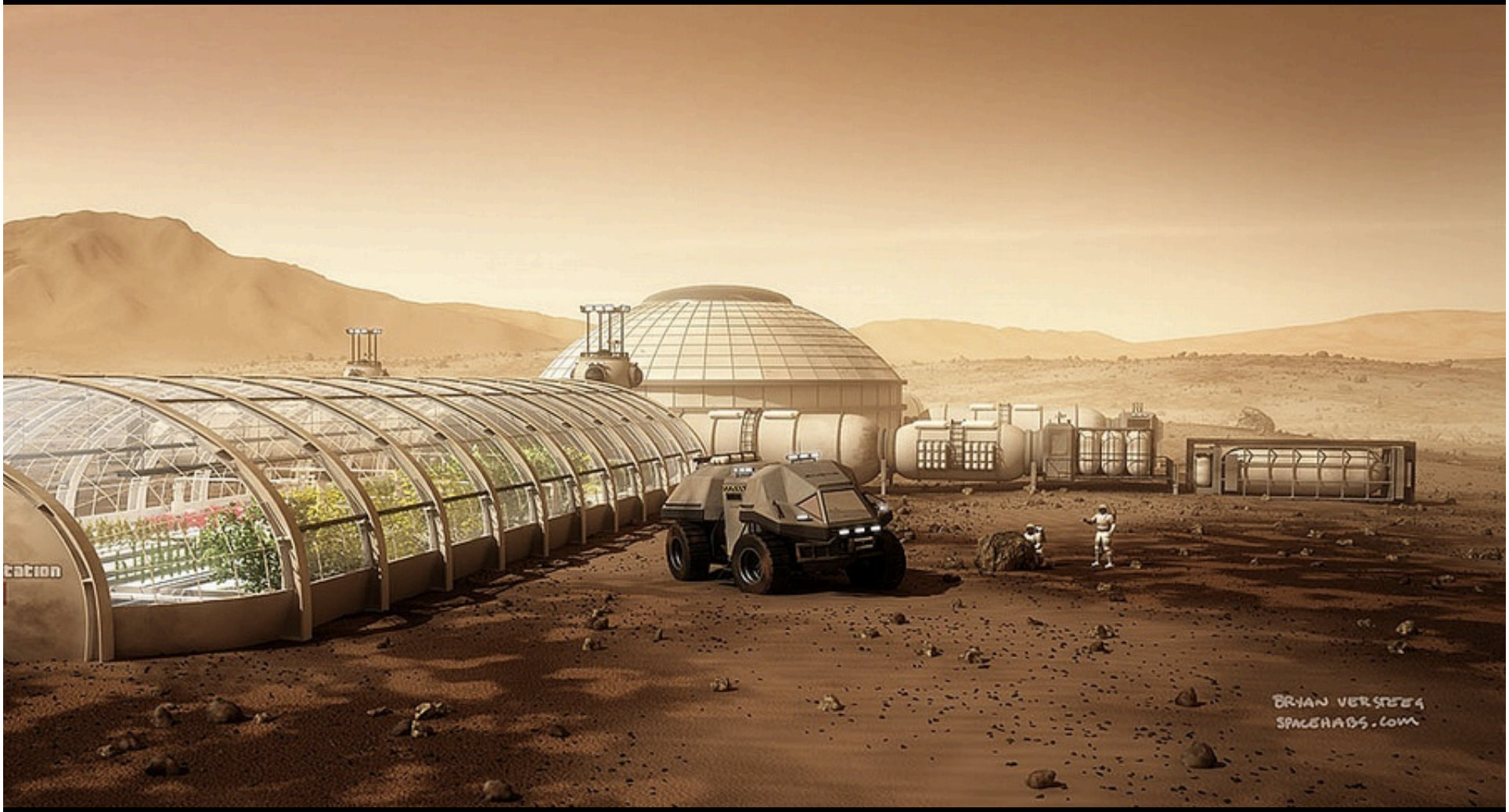
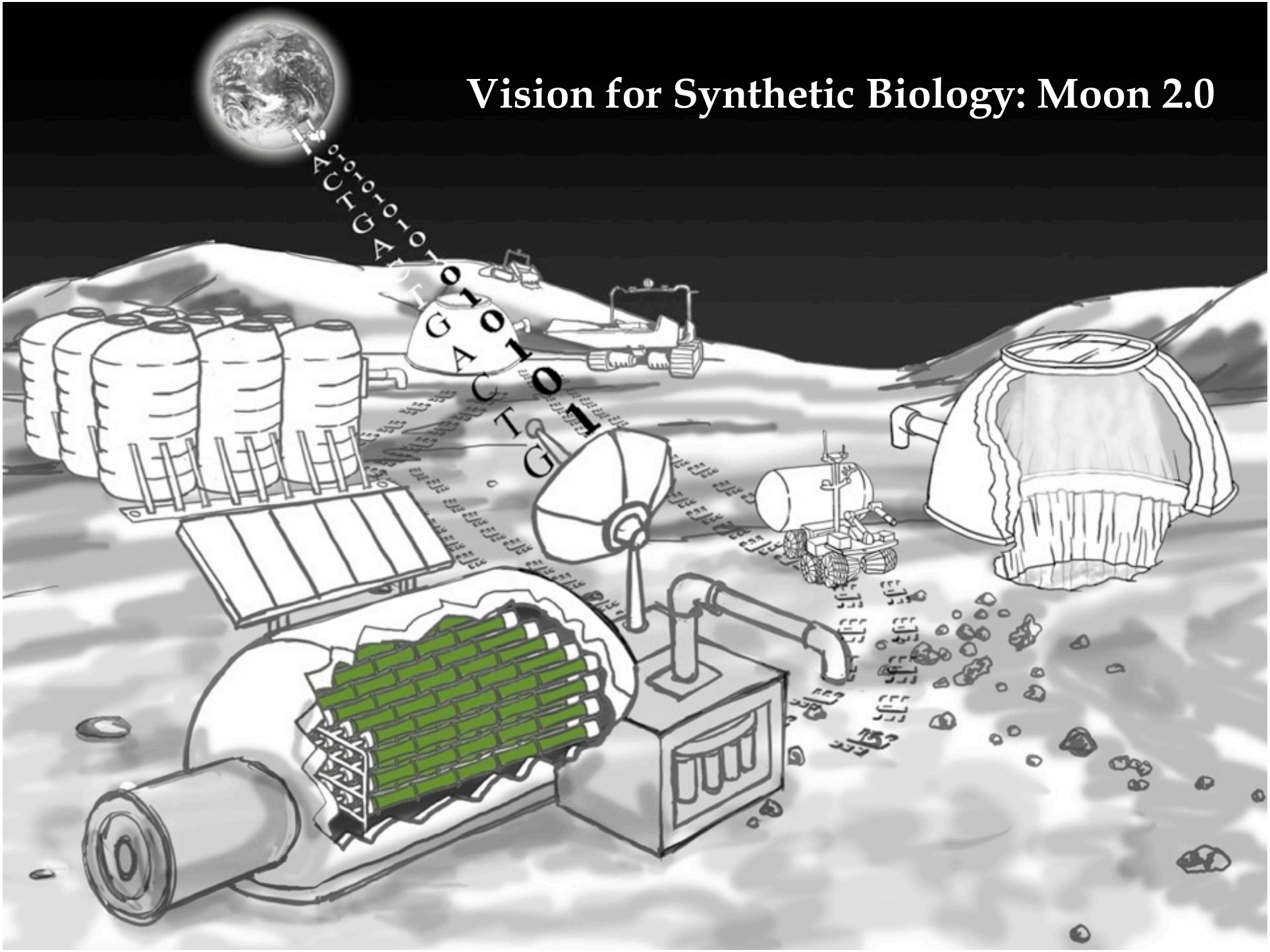
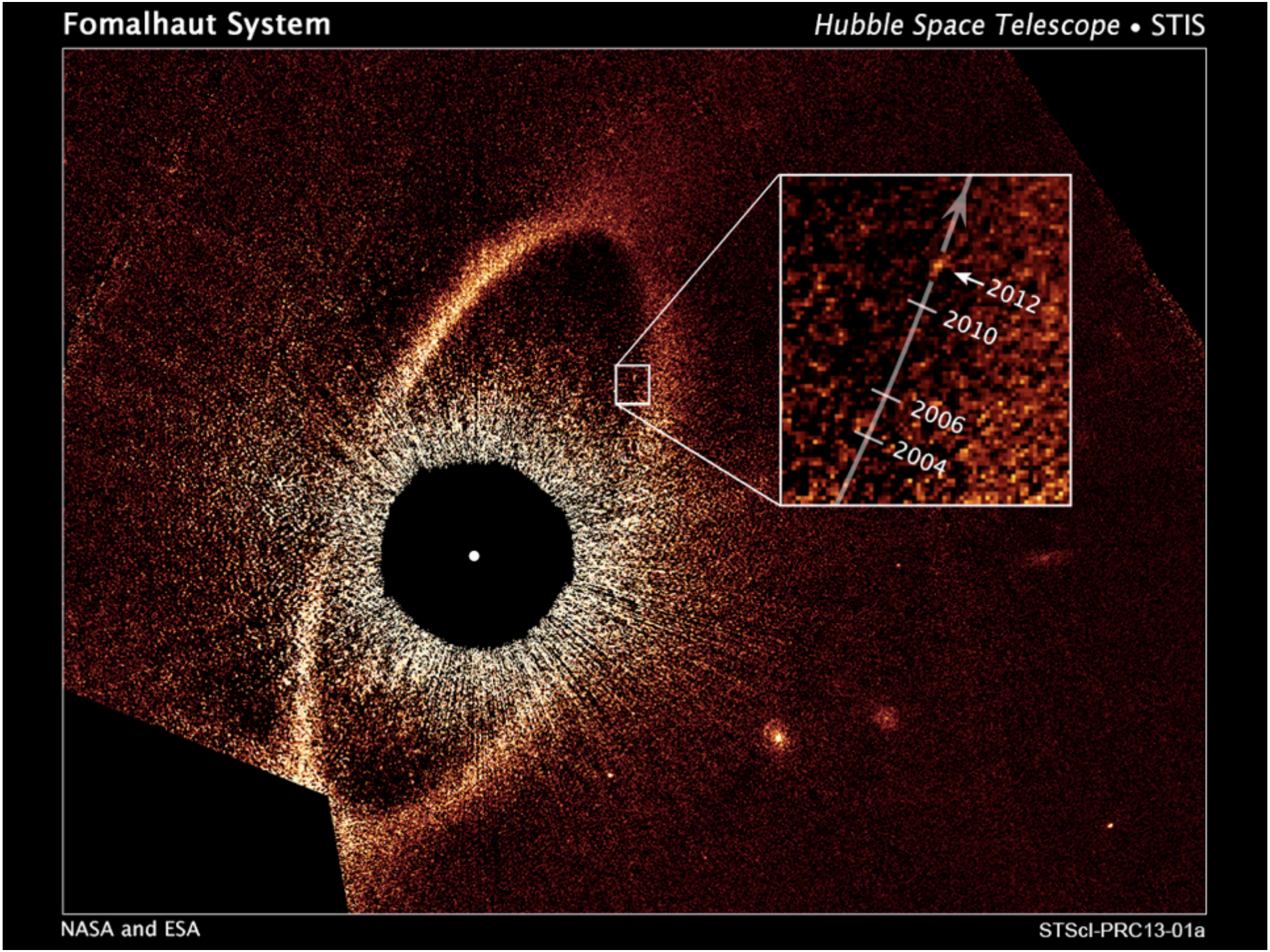


Image: Bryan Versteeg/Spacehabs.com

Image: ESA / Foster + Partners

Vision for Synthetic Biology: Moon 2.0




Fomalhaut System
Hubble Space Telescope • STIS
2012
2010
2006
2004
NASA and ESA
STScI-PRC13-01a


THE ECONOMICS OF NEOS
NASA RESEARCH PARK
MOFFETT FIELD, CA
SEPT 6 & 7, 2014
Workshop Summary
NASA